Geophysical Retrievals Using All-Sky and Clear-Sky Radiance Rates from 10 Years of AIRS Data

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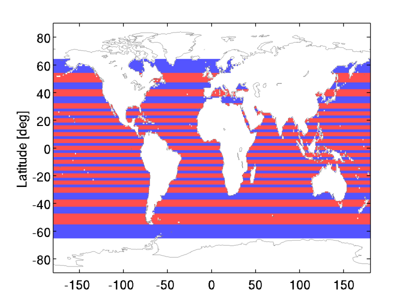
Talk Outline

- AIRS radiometric stability estimates from climate trending using AIRS zonally averaged over-ocean clear-sky radiance data
  - Develop robust OEM approach for AIRS trends using radiance derivatives and averaged data.
  - Want well understood error characteristics and ability to reprocess many many times.
- Develop OEM approach for climate trending using AIRS zonally averaged radiances from cloudy scenes.
- Extending the climate record : comparing AIRS and CrIS SNO
- Studying climate variability
  - Stochastic forcing in AIRS data

Data Sets

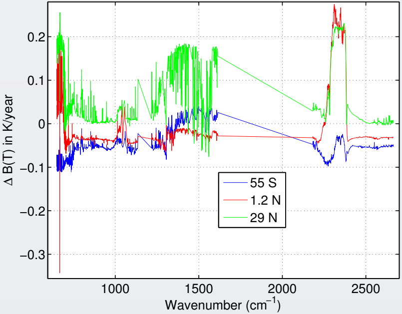
- Calibration Stability Set (Clear):
  - Clear ocean scenes, daily for 10 years.
  - Colocate ERA geophysical fields, run SARTA-clear
- Allsky Set:
  - Nadir-only all-scene subset, daily for 10 years.
  - Obs filtered using AIRS channel quality flag
  - Colocate ERA geophysical and cloud fields, run SARTA-TwoSlab (tested against Xu Liu/Xianglei Huang PCRTM/MRO cloud code)

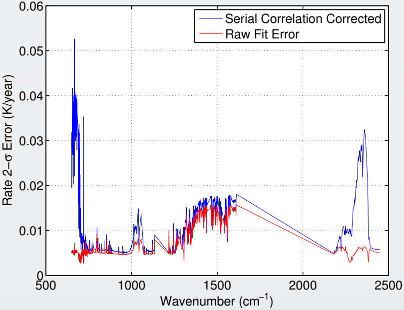


Calibration Stability Data Set

- Clear ocean scenes, binned by latitude daily for 10 years.
- Create simulation set from ERA run through SARTA, matched to every single AIRS observation.
- Determine 10-year linear BT rate (*dBT*/*dt*) from fit to 4-term sine series (seasonal and harmonics) + constant + linear rate.

Sample Linear BT Rates and Fitting Errors





OEM Retrievals

$$y = F(x) + \epsilon$$

where y are the observations ($dBT/d(time)$), x are the atmospheric state time derivatives, F is the forward model operator and ϵ is the noise. We minimize the cost function J,

$$J = |y - F(x)|^2_{S_\epsilon^{-1}} + |(x) - (x^a)|^2_R$$

which is expanded as

$$J = |y - F(x)|^T S_\epsilon^{-1} |y - F(x)| + |(x) - (x_a)|^T R |(x) - (x_a)|,$$

$$x = (K^T S_\epsilon^{-1} K + R)^{-1} (K^T S_\epsilon^{-1} (y - F(x) - R(x - x_a)),$$

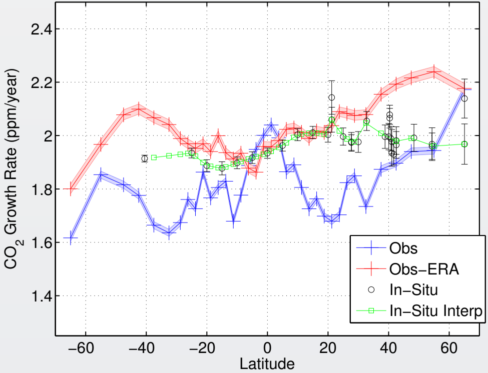
where K is the jacobian. R is either a regularization matrix (L_1 type), or is inverse of a-priori covariance (S_a^{-1}) or both. S_ϵ^{-1} is the observations covariance.

OEM Fitting Details

- CO_2, N_2O, O_3, CFC, CH_4, column spectral derivatives (and SST)
- 97-layer temperature and humidity profiles (sea surface to TOA)
- Zero a-priori x_a for all parameters
- S_ϵ^{-1} 0.001 K/year for all channels.
- When a-priori covariance used, empirically spread over several levels. Very small covariances needed (~0.01K in T, 0.01 water fraction) to stabilize profile.
- Tikhonov L_1 type regularization works very well. This is a first-derivative constraint. Determine magnitude using simulation data.

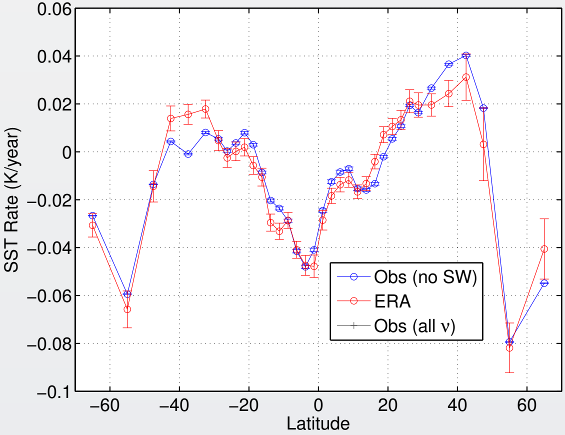
CO_2 Rate Retrieval: Highly Accurate Global Reference

BT Obs Fit for CO_2 Rate, Significant Deviations
Curious: Fit Matched ERA Simulations for CO_2 Rate (none exists)
Fix CO_2, T(z) Jacobian Co-Linearity; (CO_2^{obs} - CO_2^{sim})
Zoom for Comparison to In-Situ



SST Rate Retrievals

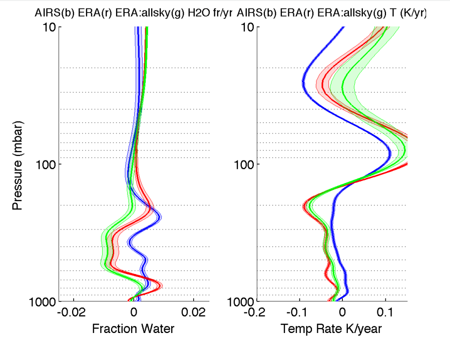
Retrieved SST Rates: No Shortwave Channels
SW channels drifting slightly wrt longwave channels



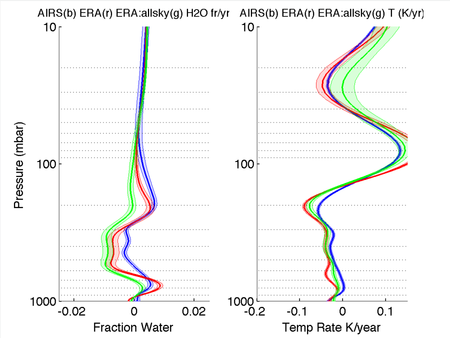
Temperature and Water Profile Rate Retrievals

Equator

Observed Rates



Simulated Rates from ERA



Our retrievals in simulation are slightly warm with high water rates. Cannot expect ERA and AIRS to match perfectly for this highly aliased clear subset. Differences also may be due to details of ENSO events, etc. Linear rates are a metric, we are not showing geophysical uncertainties for linear trends!

For more non-uniform data (mid-lat) less agreement with ERA.

Comparison of CO_2 and SST to In-Situ Values

AIRS Stability using CO_2:

- In-situ from NOAA ESRL Globalview
- Offset dBT/dt and re-fit to obtain $dCO_2/dBT = 0.07$ K/ppm
- AIRS - InSitu (all lats) = 0.005 ± 0.006 K/year
- AIRS - InSitu ($\pm$ 40 deg.) = 0.003 ± 0.004 K/year

AIRS Stability using SST:

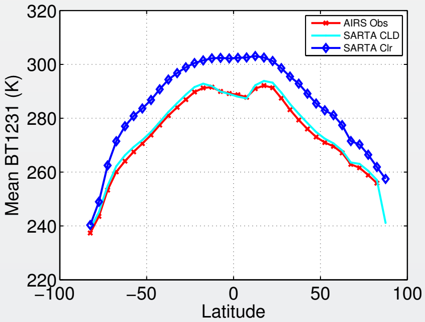
- SST from ERA, based on RGSST + GHRSST standards
- Tropical $\pm$30 deg lat considered best, buoys
- All channels: 0.010 ± 0.005 K/year
- No shortwave channels: 0.0015 ± 0.005 K/year

- AIRS BT drift from CO_2 and SST both positive, <0.01K including error bars. Larger drift in shortwave.
- 10 year rates show we have proven stability below the CLARREO requirement
- extend record with CrIS - will discuss SNO AIRS/CrIS comparisons

All-Sky Rate Retrievals

Details

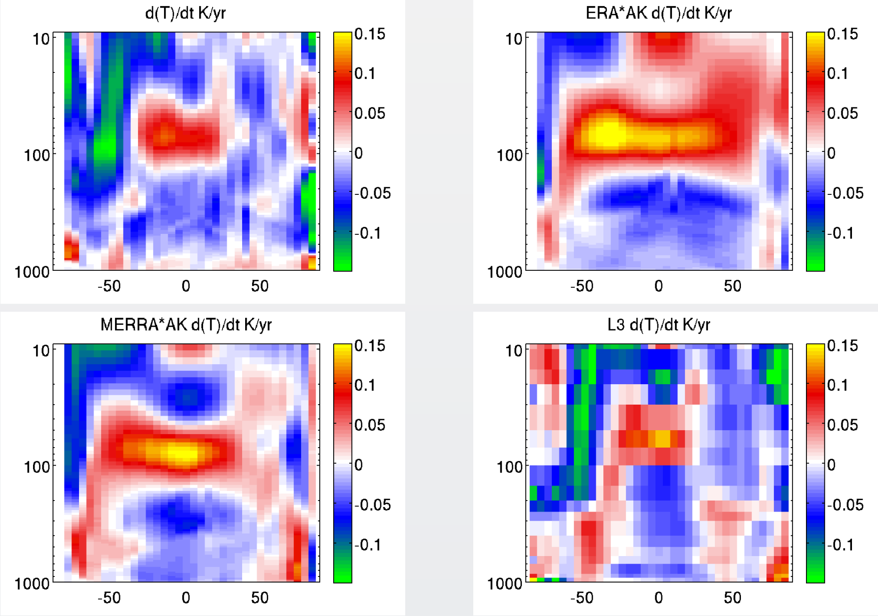
- Effort started recently, uses ERA cloud/geophysical for Jacobians
- All AIRS observations on either side of nadir for 10 years
- Daily Latitude Binned, fit each channel time series for linear rate
- Set rate uncertainty to 0.001 K.
- Minor gas, cloud parameters (optical depth, size for liquid, ice clouds) changes reasonable opposite in sign from MODIS L3 collection v5.1 climate set
- Zero A-priori, Tikhonov L_1 regularization.



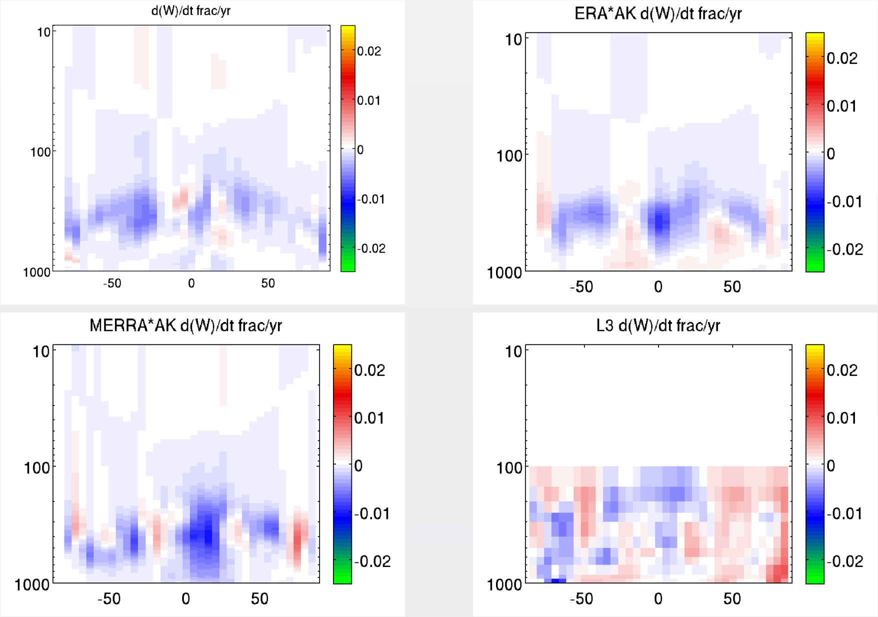
BT1231 vs Latitude

This is approach of CLARREO mission
Works quite well!!

Temperature vs ERA-Interim, MERRA, AIRS L3

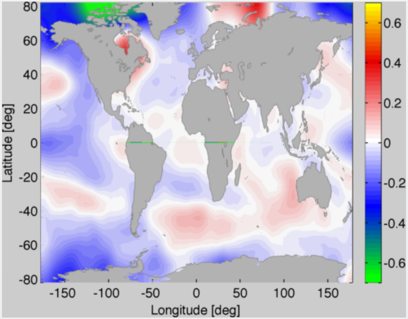


Water vs ERA-Interim, MERRA, AIRS L3

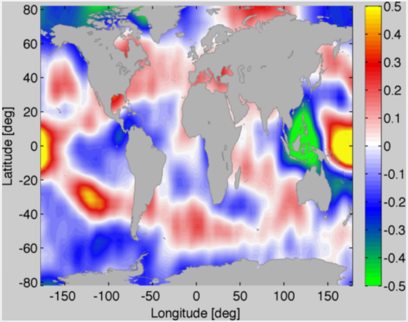


Geographic Distribution of BT1231 changes

SST Rates



All Sky



- Notice the similarities (even more pronounced for clear sky BT1231 rates!)
- Zonal averages yield very similar rates to SST rates (clear sky case)

Summary - Spectral Rates

Stability

- AIRS radiometry very stable, slight increase in extreme SW.
- Meets general requirement for climate trending (0.01K/year)
- Instrument overlaps: IASI METOP-1 now overlapped with IASI METOP-2. AIRS and CrIS overlap of 2+years, CrIS FM2 to launch in 2017
- Potential for AIRS + CrIS to provide 20 year IR climate record before CLARREO if proper overlaps occur

OEM Trends from Radiance Derivatives

- Retrievals of averaged all-sky radiance trends appear robust
- Results similar to AIRS L3, but only take a few minutes to run!
- Possibly better sampling than AIRS L3.
- Want to carefully evaluate ERA/MERRA fields against AIRS all-sky rates, for climate shifts

Intercomparing CrIS/AIRS

Motivation

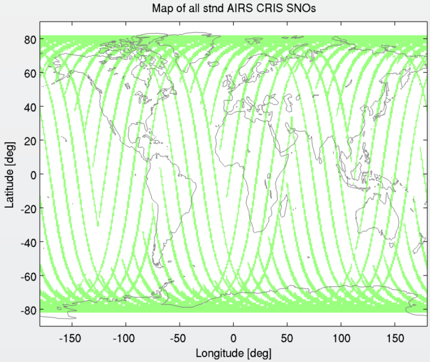
- Understand and measure bias between different sensors (for climate monitoring etc)
- AIRS launched in June 2002; possibly go on till 2022?
- CrIS launched in October 2011, 7 year lifetime with 2 more FM planned
- AIRS/CrIS flying in "similar" orbits
- Use SNO or "Simultaneous Nadir Observations" with caveats - different instruments (SRFs, noise, footprints etc), time delays!

Intercomparing CrIS/AIRS

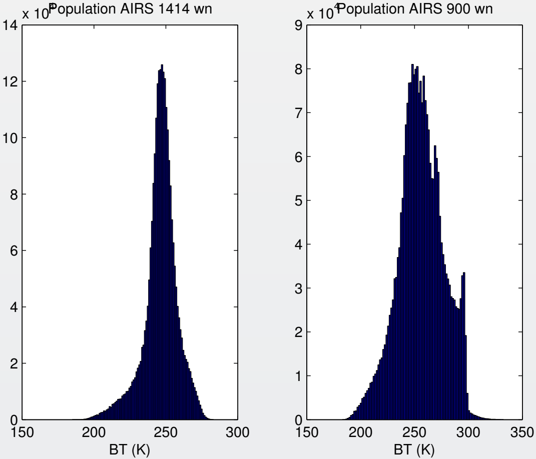
Work so far

- 2+ years of overlap (nonuniform!)
- H. Motteler : conversion AIRS SRF → CrIS ILS
- Determine bias as function of scene temperature (various channels)

Location of SNO pairs



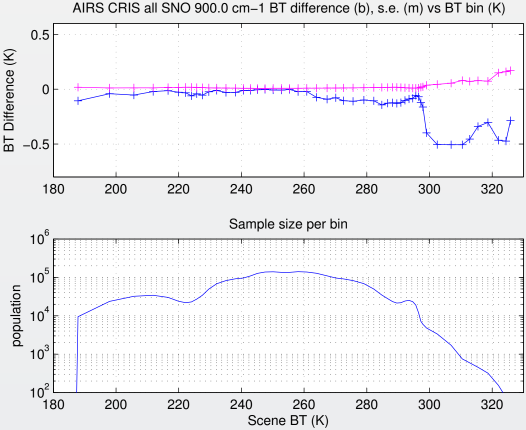
All SNO histograms, window & water channel



AIRS L1B - CRIS B.T. bias :

- 900 cm^{-1} -0.058 K. std. = 2.35 K. ste. = 0.0015 K.
- 1414 cm^{-1} +0.099 K. std. = 1.22 K. ste. = 0.0007 K.

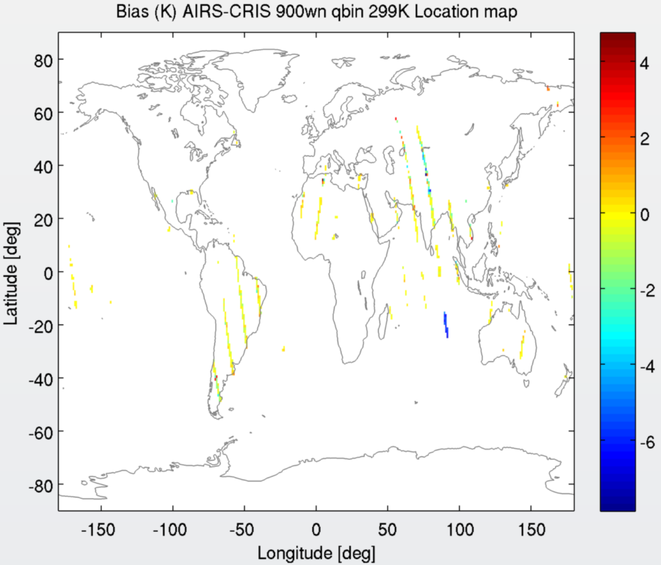
Scene Dependent Bias for a window channel



Hot scenes bias : daytime, over land heated by sun, sensors sees slightly different scenes

Largest time delay is at low latitudes, affects surface channels the most

Distribution map for large bias



Summary - AIRS/CrIS Window channel sampling bias

- AIRS CrIS bias typically better than 0.1K. Larger differences due to sample bias.
- SNO selection near the poles is nearly delay unbiased : ie amost as many AIRS obs before, as after, CrIS
- SNO selection in tropics entirely positive delay biased : AIRS always later than CrIS, sees later in diurnal cycle (cooler temps)
- This becomes significant for scenes hotter than about 270 K - above about 285 K there are NO samples with negative delay.
- For scenes hotter than about 295 K, which occur over land/islands during the day, this positive time delay bias results in high sensitivity to solar ground heating.
- Disentangling scene bias from sensor bias is very difficult.

Climate variability

Motivation

- Accurate RTA (clear/cloud sky) allow us to compare AIRS 12year observational record with radiances computed using GCM models; first moment (bias) and second moment (standard deviations) are indicators of GCM accuracy
- Instead of comparing eg observed versus modelled mean (climate) change, study variability/extreme events
- AIRS observations very non-Gaussian;

$$\gamma^n \simeq \int p(x)(x-\mu)^n dx \quad n = 3 \; skewness \quad n = 4 \; kurtosis$$

- For a Gaussian, (S) skewness = 0, (K) kurtosis = 3
- Prior work on eg SST and sea level data, and 300 mb vorticity model fields shows
  - $K \geq 3/2S^2 - r$
  - extremes : power law in tails $pdf(x) = x^{-\alpha}$ rather than e^{-x^2}

Stochastic Models

(P. Sura, FSU)

Take dynamics (forcings, linear terms, nonlinear terms) equations and separate out into slow and fast scales; the nonlinear interaction of fast scales leads to a SDE

Multiplicative noise in stochastically forced models can be shown to reproduce non-Gaussian statistics and power law behavior in PDF tails

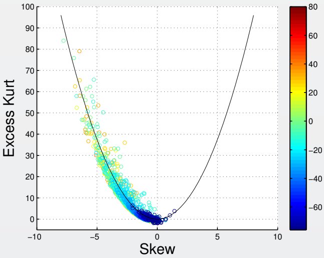
$$\frac{dx}{dt} = a(x(t)) + b(x(t))\eta(t)$$

where a = deterministic slow processes, while $b\eta$ represents state dependent multiplicative noise [as opposed to state independent additive noise $a(x(t)) + \eta(t)$]; $\eta(t)$ is Gaussian white noise

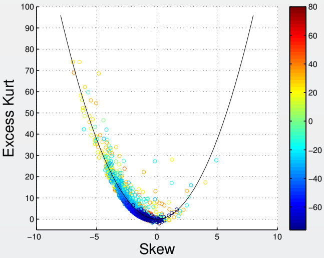
Time dependent probability distribution function can be derived from SDE, from which the $K \geq \frac{3}{2}S^2 + B$ relationship and power law tails $pdf(x) = x^{-\alpha}$ for large x can be derived

AIRS data : Kurtosis vs Skewness

AllSky Nadir Footprints Summer Kurt vs Skew for 1231 cm^{-1}



OBS



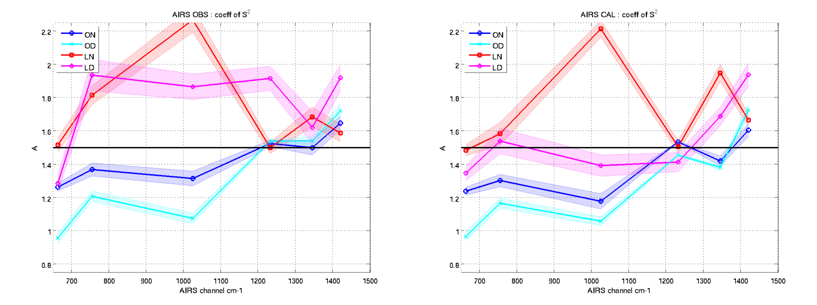
CAL

AIRS data

- each channel AIRS radiance is convolution over T(z),WV(z),stemp,trace gases, clouds
- "easier" to start with Calibration Stability Set (clear sky)
- still see similar *K vs S* plots, less skewness, but not Gaussian

ClearSky (Winter (DJF)) K vs S

coeff of S^2 (OBS) coeff of S^2 (CAL)

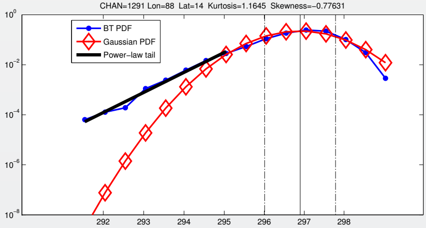


- 1231 cm-1, 1419 cm-1 and 1614 cm-1 channels have coeff slightly larger than 3/2
- 667 cm-1 channel is upper strat, very quiet; 1000 cm-1 channel is O3
- plots change as a function of season
- plots change for allsky

Power Law Tails

Main points

- Clear Obs and Cals : Expected $K = 3/2S^2$ behavior in window, WV chans; O3, T chans different!
- Allsky Obs and Cals : Typically $K \leq 1.4S^2$, except for 1614 cm-1 channel
- Power law behavior in cold tails (cloud leakage?) and in hot tails



1231 cm^{-1} channel, Tropical Pacific

THE END